

## Cosmic Ray

If it had a mind (and an ego), then it might claim to be directly descended from the Big Bang (but aren't we all?). Instead, let's ignore what it thinks and begin 4.6 billion years ago.

The hydrogen atom floated in space as a miniscule fragment of a molecular cloud of dust and gas, approximately 3.25 light-years across (call it 19 trillion miles). Drawn by the force of gravity, this mass of mostly hydrogen and helium (with a small amount of other elements mixed in) collapsed and coalesced into our favorite star (the Sun. apologies to all you Arcturus fans out there), leaving just 0.1% left to form all the planets, dwarf planets, moons, centaurs, and asteroids.

It took 100 million years of outer space bumper pool before the inner planets (including Earth) to form and another 200 million years after that before Earth cooled down enough for solid rock to appear.

Just 3.8 billion years ago, the oldest known life on Earth developed (hey Auntie Archaea!) and the Sun had settled to a radius of only 433,000 miles. Each second, 600 million tons of hydrogen atoms squash together in that compressed thermonuclear oven, at 15.7 million degrees Kelvin (or  $2.82 \times 10^7$  Fahrenheit, or who-gives-a-crap Celsius), converting to helium and releasing vast amounts of energy.

But that one hydrogen atom, while avoiding that fate for billions of years, isn't completely unaffected. The torrent of energy streaming from the core strips its electron, leaving a single proton (yes, a cation. Unleash the HYDRON, I DECLARE!)

From the core, that proton is pushed to the radioactive zone. Over a billion years, it drifts across 200,000 miles as the temperature drops to only 1.5 million Kelvin ( $2.7 \times 10^6$  F). Gliding through the tachocline and transitioning to the convection zone the proton encounters a cooler and cooler environment (like when you and your spouse ran into your ex-partner down at the farmer's market last Saturday). The temperature plummets to only 9,800 degrees Fahrenheit as it passes into the photosphere.

Lingering in the photosphere, our little proton churns through the chromosphere, corona, and heliosphere (sure it's close to the beach, but where would you buy groceries?). And maybe back again, as gravity fights with the electromagnetic discharge, pushing and pulling against the particles of the solar atmosphere.

And during solar cycle 25, (a somewhat arbitrary number, just assigned by some newly evolved primates on Earth that started counting the cycles from 1755), the proton finally joined its own solar flare. Now, number 25 was nice, but never really made a name for itself. Not like ole number 23.

Solar cycle 23 had The Bastille Day solar storm that began on (you guessed it already) July 14, 2000. That huge solar flare of magnitude X5.7 caused a coronal mass ejection and corresponding solar particle event. When it hit Earth, auroras were seen as far south as Texas, satellites were damaged, and radio communication was disrupted (Casey Kasem, where are you?!).

Hydrons everywhere dreamed of being part of a storm as impactful as The Bastille Day, but fate intervenes.

As we said, our proton was in solar cycle 25. And its solar flare, on March 30, 2022, was only a magnitude X1.3. Not bad, all considering, but also not good. Quite pedestrian really. They made the best

of it though. It was still large enough for a solar particle event and the good proton was flung out into space at nearly the speed of light.

The added energy transforms the proton into a solar energetic particle (SEP), aka a solar cosmic ray.

For an unmoving, and unmoved, observer, light would appear to take approximately 8 minutes and 20 seconds to travel the 93 million miles from the Sun to the Earth. Maybe a little less when the Earth is at perihelion and maybe a little more when it is at aphelion, but March 30 is halfway between those, so our estimate is probably good. And our particle is not as fast as light (what is? Wink, wink, nudge, nudge), so it would take a bit longer, say around 9 minutes and 16 seconds. (Don't hold me to that estimate though, we still need to do peer review.)

Of course, a moving observer, say Albert Einstein riding that proton like Ron Turcotte on Secretariat, would experience time differently. At 90% the speed of light, the ride from the Sun to Earth would seem to pass in only four and a half minutes. (Barely enough time to honk your horn at Venus for not moving fast enough when the light turned green.) So, the SEP is only four and half minutes older, while the people on Earth have aged over 8 minutes, when the damn thing slams into Earth's atmosphere like a penny hitting the sidewalk after being dropped from the Empire State Building.

Unlike the penny, which, due to wind resistance, hits a terminal velocity that would be unlikely to damage anything, the cosmic ray collides with a nitrogen atom nucleus in the atmosphere at relativistic speeds. The high energy collision results in a charged pion, which decays in about twenty-six nanoseconds into a muon and a muon neutrino (faster than a speeding bullet? Yes. Faster than the speed of light? No!)

That muon though.

That muon doesn't seem so special. A muon is 206 times the size of an electron and 10,000 muons hit every square meter of Earth every minute. It travels in the same direction as the original cosmic ray, but even faster ... 99.999% the speed of light.

Through the exosphere it goes, the thermosphere, the mesosphere, the stratosphere, and even the troposphere. We would only expect it to live two millionths of a second before it decays again into an electron and neutrinos, but with relativistic time dilation that is plenty of time for it to reach the surface.

Where will it hit?

North America, towards Indiana (oh no!), wait, actually it's Illinois (whew!). It could be Chicago ... Nope, it will be a bit northeast (darn, hoping to see Wrigley). But still just a 35-minute drive (or a 9 hour walk) from the Cloud Gate. Closer and closer it comes.

If you want to meet it, take exit 1B of I-290. Not East towards Busse Woods, but West. 425 North Martingale Road. 42 degrees 2 minutes and 9.42 seconds North and 88 degrees 2 minute and 1.068 seconds West.

No wind deflects it, no glass reflects it. Through the roof of the office building it goes, through another floor and another. To suite 600, it comes through the ceiling tile, a florescent light fixture, the top of a cabinet, the server housing and finally, finally, finally, after 93 million miles, it expends its energy when it interacts with a silicon wafer in a computer in the offices of the Society of Actuaries.

What are the odds that the muon would hit any particular transistor on a chip with billions? Literally astronomical.

That transistor, one bit in a string of eight to make one byte, is only ten nanometers (10 billionths of a meter) across. Set to "1", the second "1" in a 00000110 byte, the transistor really thought it had found its purpose. But then that rotten muon comes along and ruins everything. Interacting with that muon causes a bit flip (you heard me, a so-called single-event upset). Now the transistor is a "0".

Those Bynars among us already see the implication. (As we all know, the native sentients of the planet Bynaus communicate in a binary language.) Changing 00000110 to 00000100 converts the decimal value from a "6" to a "4".

And that's why I failed exam IFM last March.